IV. *On Flame Spectra.*

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Communicated by ARTHUR SCHUSTER, *F.R.S.*

Received May 28,—Read June 16, 1904.

[PLATE 4.]

IN the course of a photometrical investigation of flames, which had been coloured by injecting the spray from saline solutions into the gas to be burnt, M. GOUY discovered, in the spectra of the flames, several new lines belonging to the metals contained in the solution.* Instead of appearing throughout the whole flame, as did the previously known lines, these new lines were only emitted in the vicinity of the blue inner cone—the origin of the Swan spectrum. The observations of M. GOUY were limited to the examination of certain lines of the visible portion of the spectrum, and, with the advice of Professor SCHUSTER and under his direction, I have taken up this study with the object of extending it, by means of photography, to the ultra-violet portion of the spectrum and also of detecting lines which are too feeble to be visible to the eye.

I. METHOD OF PRODUCING THE FLAME.

The method employed for the production of the flame is, in short, that which has been introduced by M. GOUY, and described by him in his memoir, to which reference should be made for a more detailed description. The very slight modifications which have been made in the apparatus of this scientist are due to the necessity of having an arrangement which should be as automatic as possible during the eight hours which were often found necessary for the photographic exposures. These modifications, however, have an important bearing upon the success of the experiments.

Referring to the diagram, A is a glass globe, having three necks at B, C, and D. Into the neck at B is fitted the sprayer P, which consists of two concentric tubes, which have been drawn out together very finely at one end. The inner tube, through which the liquid is blown, is connected by means of indiarubber tubing to the lower neck C of the globe A, whilst the outer tube of the sprayer is in communication with a supply of compressed air. Part of the spray of the liquid falls to the bottom of the globe A, whilst a much smaller portion is carried away by the stream of air and passes into the upper globe E, where again the largest drops of the liquid fall down. Communication is established between the globes E and A by means of a vertical glass tube, in the wall of which there is a circular aperture O. The object of this aperture is to afford a free passage to the mixture of air and the spray of the solution in the event of a drop of the liquid, which deposits on the walls of the tube, collecting at its lower end. One thus avoids all oscillatory movements of the flame due to the air forcing its way through the tube intermittently. The drops which do collect at the end of the tube simply fall back into the globe A when they have become sufficiently heavy, and thus do not interfere with the passage of the air and spray into the globe E. An indiarubber tube then conveys the mixture to one of the branches of a Y-shaped tube, another branch of which is connected to the coal-gas supply. The third branch is fitted at G into a wider tube GH, in which the heavier liquid particles have a further opportunity of settling down. These collect in the lower portion of the tube, whilst the gaseous mixture passes directly onwards through H to the burner. The burner consists of a horizontal, cylindrical tube of

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* 'Annales de Chimie et de Physique,' 5th Series, vol. XVIII., 1879.

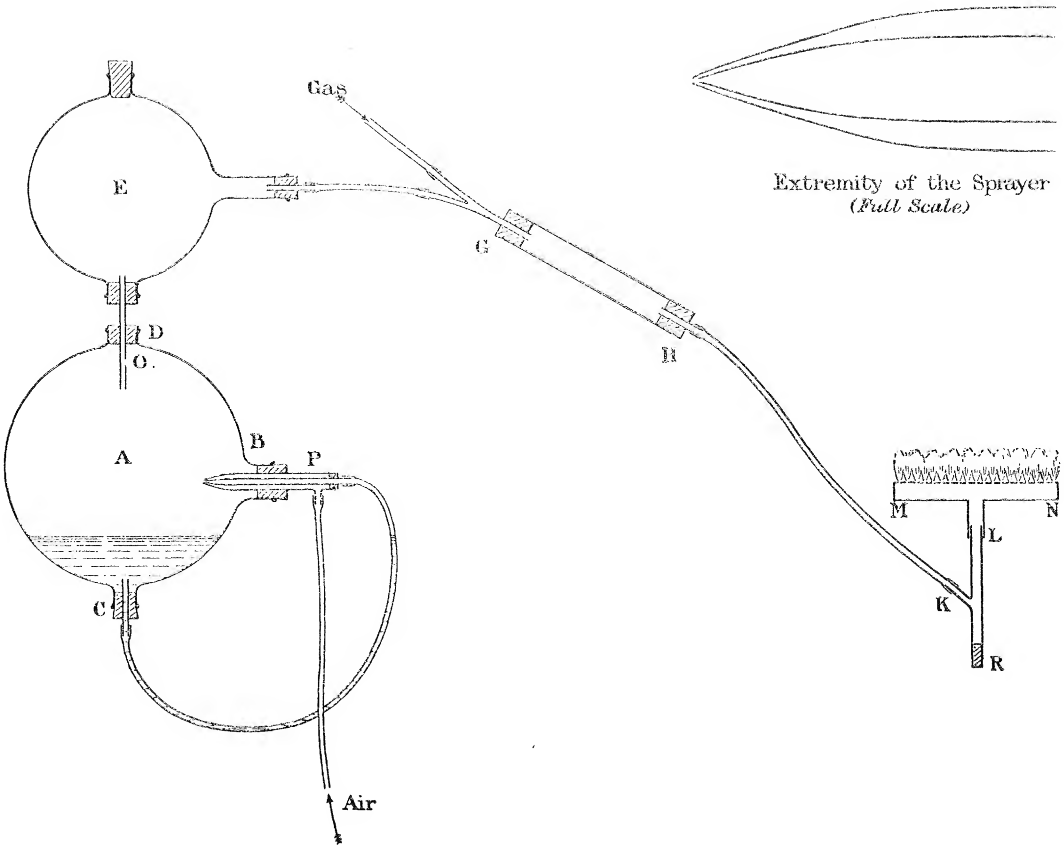

Fig. 1.

copper, perforated with 30 holes, each of about 2 millims. diameter, arranged along a straight line, parallel to the axis of the tube. In order to avoid any accumulation of water in the indiarubber tube which conveys the mixture to the burner, it is advisable to fix the tube GH at a level slightly higher than that of the burner. The mixture arrives at the burner from the branch K of a three-way glass tube. Any liquid which may condense here will fall into the closed tube R, the contents of which may be easily removed.

The flame is really composed of 30 small flames, each of which, by carefully regulating the supply of gas, may be made to have the same height. Owing to the transparency of the flames, the total intensity of the light will be considerably increased in the direction of the length of the burner.

If reference be made to the description which M. GOUY has given of his apparatus, it will be noticed that I have suppressed the regulator, which had been found necessary when making delicate photometrical measurements. But this accessory would have made it imperative for the experimenter to be in constant attendance, and in the present case this was impossible on account of the long exposures which had to be made. However, the apparatus was found to be very steady in its working, owing chiefly to the employment of a very constant air supply. In one stage of the work I used a large gas-holder which had a capacity of 1 cubic metre, and which could be filled with air under a pressure of four atmospheres. At another time a public supply of compressed air at constant pressure was utilized. All that was necessary was to adjust the gas supply from time to time in order to keep the flame at a fixed height. The quantity of air used was about 1 cubic metre (under atmospheric pressure) per hour.

Solutions employed.—In all cases where this has been possible, a solution of the chloride of the metal to be investigated has been used. Only in those cases where the chloride is but slightly soluble have other solutions been found necessary. However, the particular salt taken is mentioned at the commencement of all the descriptions of the different spectra examined. The solutions have been made as strong as possible, but not so strong that the salt has crystallized out during the working of the apparatus. When crystallization has occurred, a small addition of warm, distilled water has been sufficient to overcome the inconvenience. The concentration of the solution is of considerable importance, for upon it depends the intensity of the lines of the spectrum; certain of them may even disappear completely if the solution is too dilute. For instance, the green lithium line 4972, which had not hitherto been noticed in the flame, becomes extremely bright when a strong solution of the chloride of this metal is used. Again, an experiment made with the chloride of calcium showed a very marked difference in the intensity of the lines on two photographs, obtained under precisely similar conditions, except that in one case a dilute solution (10 per cent.) and in the other a saturated solution was employed. It is, above all, necessary to secure that as much as possible of the spray of the solution shall reach the flame. The sprayer described by M. GOUY works very well in this respect; that is to say, a relatively small quantity of air is able to produce a sufficiently large amount of spray. In order to ensure this condition, the annular space between the end of the inner tube and the inner wall of the outer tube should be made as small as possible.

II. SPECTROSCOPICAL APPARATUS.

Both diffraction grating and prism spectroscopes have been used in this research. The grating offers a ready means for the direct determination of wave-lengths, and, moreover, on account of its high resolving power, enables closely adjacent lines to be easily separated. This is important, since whenever a particular line is built up of several components, it is necessary to determine which of these components are present in the flame. On the other hand, with the grating, a large amount of the incident light is uselessly spent in the formation of the spectra of different orders. Consequently the prism spectroscope has been employed for mapping these lines which are too weak to be detected on the photographs taken with the grating spectroscope.

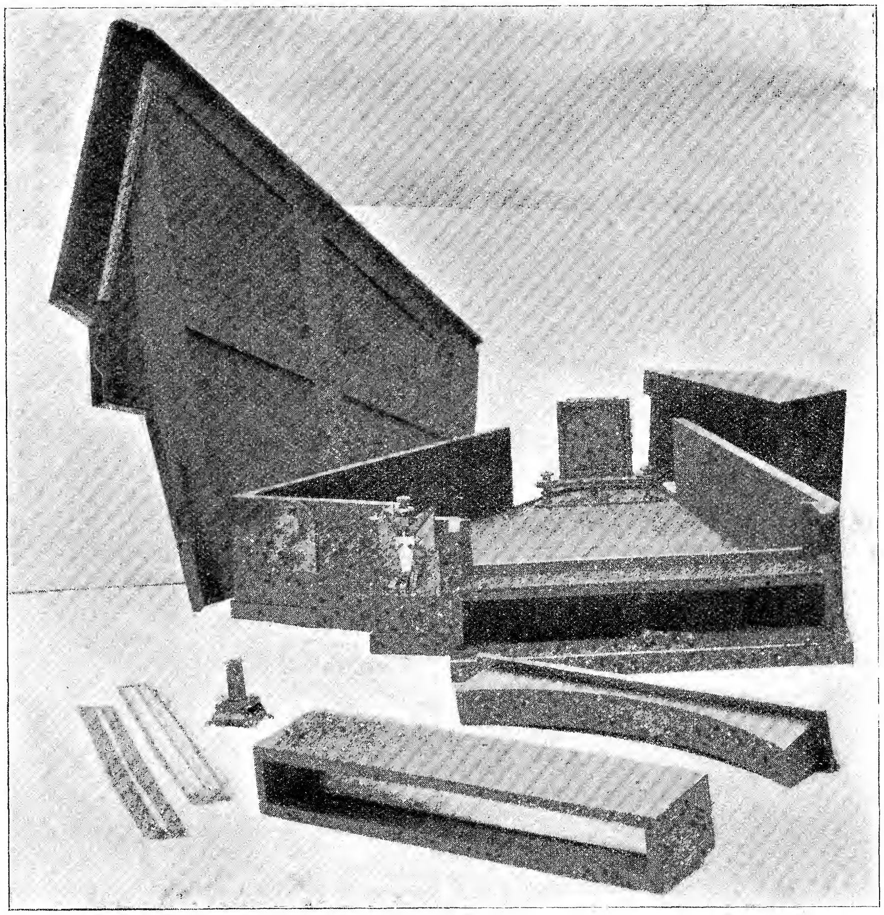

Fig. 2.

(1.) *Rowland Grating Spectroscope.*

This spectrograph, constructed for Professor SCHUSTER and made to his design by the Cambridge Scientific Instrument Company, is enclosed within a light-tight case, the greatest length of which is rather larger than 1 metre. At one end is the grating, fixed vertically on a platform, which can be moved either in a vertical or in a horizontal direction by means of three clamping screws. For this purpose the platform is drilled with three large holes, through which pass the vertical bolts. The lower ends of these bolts are screwed into a metal plate, which is itself firmly fixed to the base of the box. Two nuts on each bolt serve to clamp the platform at any desired height. At the other end of the case there is a dark slide, in which the photographic film is placed, or in which the eye-piece used in the adjustment of the grating and for eye observations may be fitted. The eye-piece is held in place by springs, and may be moved along two grooved iron rails which have been bent to the requisite curvature. When films are used, they are firmly pressed against these rails by means of a piece of curved wood, which closes the slide securely.

There are, in addition, two circular openings in the case, corresponding respectively to the positions to be occupied by the slit, when it is desired to have on the film either the first-order spectrum or the second-order spectrum in their full extent. A system of regulating screws, placed near each of these two openings and against which the tube carrying the slit is made to bear, allow the exact position of the slit to be re-found, both as regards possible vertical displacements and horizontal displacements, when the slit has to be moved from one aperture to the other.

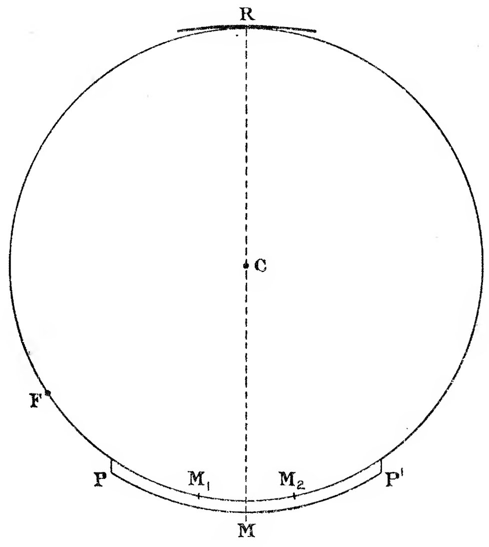

Fig. 3.

The grating itself is a fine Rowland concave grating of 15,000 lines to the inch, and having a ruled length of 3·5 inches. Its radius of curvature is 1 metre, and on the films used a length of 1 millim. corresponds to a difference of wave-length of about 16·8 Ångström units.

Adjustment of the Grating.—As is well known, the series of images of the slit formed by diffraction will all lie on a cylindrical surface to which the slit and the grating are both tangents. The diameter of this cylinder is equal to the radius of curvature of the grating, and the normal RM (fig. 3) to the grating should coincide with a diameter of the cylinder. To perform the adjustment, one begins by ascertaining that the centre of the ruled portion of the grating is in a horizontal plane which divides the film into two equal halves; then one places a wire cross at a point M_1, situated close to the point M, the centre of the film, both points M and M_1 lying on the horizontal line dividing the film into two equal halves. The grating, acting simply as a mirror, forms an image M_2 of the cross, and, by means of the levelling screws of the grating, M_2 is brought to the same height as M_1. Also, the image of the wires should be perfectly sharp, and this is realised by sliding the platform carrying the grating either to or away from M, over the clamping screws. Then, when the points M_1 and M_2 are symmetrically situated about the point M, the normal to the grating passes through M and lies in the horizontal plane dividing the film into equal portions. Moreover, the distance of the grating from the film is equal to the radius of curvature of the grating.

The slit is then illuminated by means of a source of light which gives a line spectrum, and the slit is adjusted in the tube until the lines are seen clearly through the observing eye-piece, which is focussed on the surface with which the film will afterwards coincide.

The adjustment should then be complete, but this is generally found not to be the case, on account of the different refrangibilities of the eye for the different colours. The further adjustment is then made by the help of photography. The three possible means of adjustment at one's disposal are as follows:—(1) The displacement of the slit in its tube—this has exactly the same effect for all parts of the spectrum; (2) the displacement of the grating parallel to itself; and (3) the rotation of the grating about a vertical axis passing through its centre. The last two motions differ from the first in producing effects which vary in magnitude for different parts of the spectrum.

In this way it is possible to correct the want of sharpness either of the whole spectrum or of any particular portion thereof. By using the three means of adjustment methodically, it is possible to secure perfect adjustment after a certain number of trials. A useful plan adopted was to use the grating as a mirror, and by means of the motion on a screen of the image of a small flame to estimate the angle through which the grating was rotated at any time, or, when the grating had only to be displaced parallel to itself, to make sure that there was no rotation about its vertical axis. In this way it was easy to increase or decrease any particular displacement by a desired amount.

Comparison Spectra.—Whenever a flame spectrum has been photographed, a comparison spectrum has been photographed with it, this being either the spark or the arc spectrum of the metal under investigation. It was important, in order to avoid any accidental relative displacements of the lines, that the burner and the electric arc or spark should lie exactly in a straight line with the centre of the grating. This condition was realised in the following manner:—The electrodes E, E′ are adjusted so that the gap between them is at the same height as the centre of the grating (and therefore at the same height as the centre of the photographic film). The slit F then being opened widely and the spark set going between E and

E′, one can see on the grating itself the luminous trace of the incident pencil of light. The spark is then moved about until this trace occupies exactly the central part of the surface of the grating. The burner is then lit and placed at B, between the spark and the slit. The burner is then displaced laterally and rotated about a vertical axis until the inverted image of the flame that one sees on looking at the grating is as small as possible, this being the case when the series of small elementary flames is in a straight line with the slit and at the same time the image is superposed on the luminous trace due to the spark. It only remains now to place two lenses, one at L, between the burner and the slit, so as to illuminate the whole surface of the grating, and the other at L′, between the burner and the spark, in order to concentrate the light of the spark at the centre of the burner. The distances are so arranged that a small image of the spark is formed at the slit, so that the whole surface of the grating is also illuminated by the light of the spark. The height of the two lenses is adjusted until the spectrum of the spark falls exactly in the centre of the field of view of the observing eye-piece. As to the height of the burner, this is determined so as to obtain on the photographic plate the spectrum of the two principal interesting regions of the flame, viz., the inner cone and the flame properly so-called. A metallic wire is fixed on a level with the tips of the small cones and the burner is raised or lowered until the dark line produced by this wire across the spectrum of the flame is in the centre of the field of the eye-piece. It is almost unnecessary to add that when the comparison spectrum was the arc spectrum, the adjustment was made in exactly the same way by previously using the two carbons as sparking electrodes.

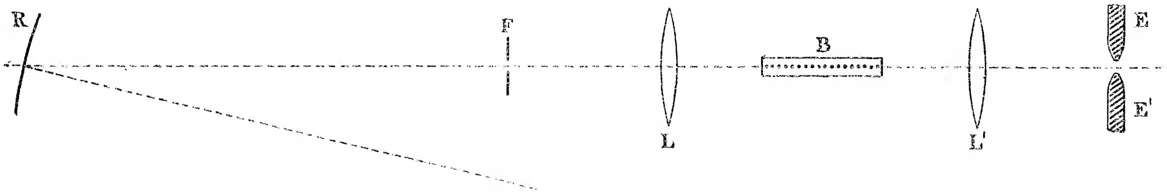

Fig. 4.

This procedure has always given a very satisfactory coincidence between the lines of the two spectra, and has enabled me to avoid the accidental displacements which were observed before these precautions were taken.

On account of the extremely long time of exposure with the flame, the comparison spectrum was obtained in the middle of this exposure, so as to establish a mean position of the lines in the event of variations in the temperature of the apparatus intervening to produce a widening of the lines of the flame. During the exposure for the arc or the spark, the shutter of the dark slide was replaced by a screen provided with a central aperture, 3 or 4 millims. wide, running along its whole length, an exactly complementary screen to this being used during the exposure for the flame.

(2.) *The Prism Spectrographs.*

Each of the spectra to be afterwards described has been obtained afresh in the Physical Research Laboratory at the Sorbonne by means of two prism-spectrographs. One of these, intended for the visible portion of the spectrum, is provided with a Rutherford-Steinheil prism. The other, which answers the requirements of EDER,[*] is composed of two lenses and an excellent prism of quartz, worked by M. WERLEIN, of Paris, and allows the whole spectrum to be obtained on one plate. I will not describe the adjustment of this apparatus, the details of which will be found very clearly and practically stated in the paper of M. HEMSALECH.[†]

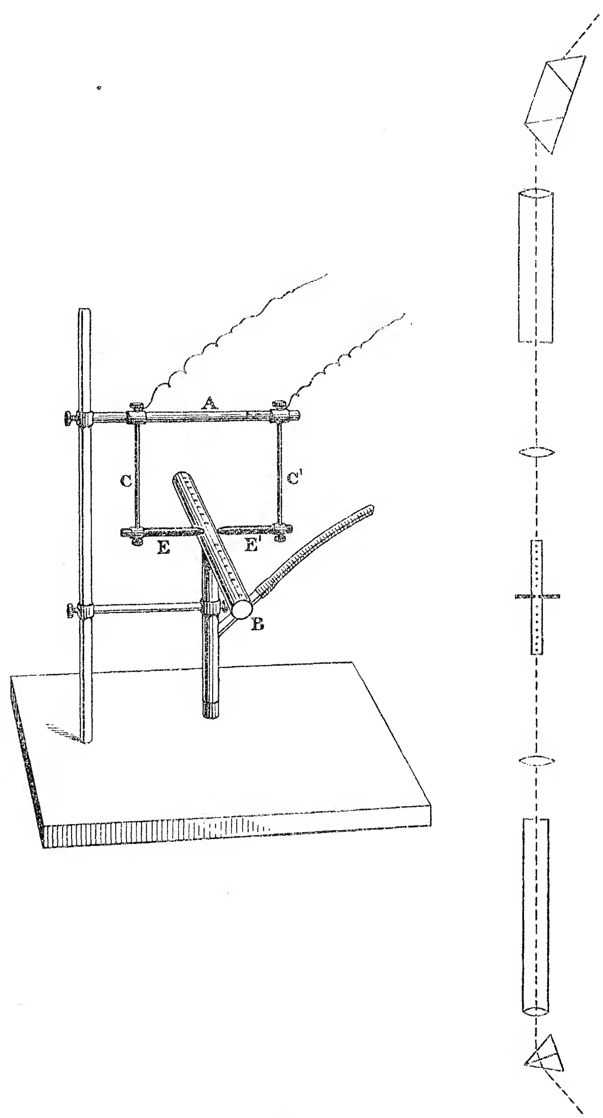

Fig. 5.

The arrangements for obtaining the comparison spectra in this case were as follows:—The burner B, the central holes of which had been closed up, was fixed upon a support which also carried a bar of insulating material A, along which the electrodes E, E′ could slide. There would then be a gap in the centre of the flame which would be occupied by the electrodes, and thus the spark could be obtained in the axis of the flame and exactly at the same height as the tips of the small blue cones. A single lens served to direct the light of the flame or the spark into the spectroscope. The two spectroscopes were placed one on either side of the burner, as indicated in the figure, and they could thus be used simultaneously. Here, as in the case of the grating photographs, the spark spectrum fell in the centre of the spectrum of the flame, dividing it into two regions, of which the one corresponded to the inner cone, while the other corresponded to the upper portion of the flame.

Photographic Methods.—For the grating photographs I have used EDWARDS' orthochromatic films, developed with amidol and sodium sulphite, and for the prism photographs LUMIÈRE plates, series A and B, one series being sensitive to the yellow and green and the other to the yellow and red, CRISTALLOS being used as the developer. All these preparations have given good results, except for their known insensitiveness in the green region of the spectrum. This inconvenience I have not been able to overcome by means of sensitizing agents.

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[*] 'Wiener Denkschr.,' 57 (1890).

[†] 'Sur les Spectres d'Etincelles,' Paris, HERMANN.

The times of exposure have been eight hours on the average with the grating, from three to four hours with the glass prism, and six hours with the quartz prism. It would certainly be advantageous to prolong these exposures still further for the ultra-violet portion of the spectrum, where the quartz apparatus gives a greater intensity and also a greater number of lines than the grating.

III. METHODS OF MEASUREMENT.

I have used several methods for measuring the photographs obtained. In the case of the grating photographs the simplest method consisted in finding exactly the distance between two lines, using a magnifying lens and finely pointed dividers, and transferring it to a divided scale. Knowing the difference of wave-length corresponding to 1 millim. on this scale, the difference of wave-length could then be deduced. In this way one could obtain approximate results, the maximum error of a $\frac{1}{4}$ of a millimetre in the readings corresponding to an error of 4 Ångström units. This approximation was sufficient when it was a question of determining easily recognized lines, and one had rather, as in the present case, to identify the lines of the flame spectrum with those of the adjacent and known spark spectrum of the same metal than to make an exact measurement. In certain other cases this summary method has not been sufficient, and I have then had recourse to photographs obtained with the prism spectroscopes on which the comparison spectrum was always that of the oscillatory electric spark between iron poles. The position of the line has then been obtained definitely by reference to the atlas of the iron spectrum prepared by KAYSER and RUNGE. Finally, for metals whose spectra are very rich in lines, for example the metals of the iron group, I have been compelled to use the ordinary methods of measurement. The new measuring machine described by M. KAYSER,* and which belongs to the Physical Laboratory of the University of Manchester, has been of the greatest use to me. The time needed for the measurement of a photograph is considerably shortened by its use, thanks chiefly to the automatic printing apparatus with which it is provided. Any required wave-length is obtained, as is well known, by interpolation between the wave-lengths of two neighbouring known lines.

The lines due to the carbon in the coal-gas and to the water-vapour are present in each spectrum, but, except in the case of the metals belonging to the iron group, where a considerable number of feeble lines may have been omitted, they do not cause much trouble. Their intensity is, on the whole, weak compared with that of the lines being studied, and they only extend to a small portion of the total length of the spectrum. In particular, the characteristic regularity in the disposition of the carbon bands enables them to be very easily recognized. I have besides made an exposure for 24 hours—three times the normal exposure—with the non-luminous flame produced by the apparatus working as usual, but without the addition of any salt, and the photograph thus obtained has been very useful for comparison. I have also found valuable information in the descriptions of these accessory spectra given by EDER and VALENTA.

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* 'Handbuch der Spectroscopie,' vol. i., p. 644.

As to the intensities of the lines, it is well known how uncertain their estimation must be, depending as it does upon the judgment of the observer, upon the apparatus used, and also upon the unequal sensitiveness of the photographic plate to the different rays. The numbers to be given afterwards do not claim any more than to indicate approximately the relations between the intensities of the lines in a certain region. For this purpose I have combined the results obtained from the three spectra photographed for each metal, for a very strong ultra-violet line, which would have an intensity represented by 10 in the spectrum given by the quartz prism, might only have an intensity represented by 2 in the spectrum given by the grating. This correction has been impossible in the green portion of the spectrum on account of the plate, and it is certain that in this region the errors in the estimation of the intensity are greatest.

In the following tables, in order to facilitate comparison, I have tabulated the measurements of the arc spectra made by KAYSER and RUNGE. Only those lines have been included whose wave-lengths lie between the limiting wave-lengths observed in the flame spectrum of each metal. Moreover, all those lines in the arc spectrum which are of less intensity than the weakest of those in the flame spectrum are not mentioned at all. Thus, for instance, when no line of intensity lower than 6 in the arc spectrum is found in the flame spectrum, I shall indicate for the arc spectrum only those lines which have intensities 10, 9, 8, 7, and 6, but shall include those of these intensities which are missing in the flame spectrum.

With some metals the flame spectrum contains bands of a more or less complicated nature in addition to the lines. Such is the case, for instance, with magnesium, barium, strontium, calcium, copper, tin, and manganese. The study of these bands and the nature of the compound to which they are due, forms no part of the present investigation. The accompanying tables therefore contain only the lines which are ascribed to the metals.

LITHIUM.

Salt used : Lithium Chloride.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Remarks.
Wave-length.	Intensity.	Cone.	Flame.	
6708·2	10sr	10	10	n = 3, Pal. Ses.
6103·77	10sr	5	3	n = 3, 1st S. Ses.
4972·11	6bn	3	—	n = 4, 2nd „ „
4602·37	10sr	10	3	n = 4, 1st „ „
4273·44	4n	3	—	n = 5, 2nd „ „
4132·44	8nr	6	5	n = 5, 1st „ „
3915·2	6nr	3	2	n = 6, 1st „ „
3794·9	4n	2	—	n = 7, 1st „ „
3232·77	8sr	8	8	n = 4, Pal. Ses.
2741·39	6sr	3	1	n = 5, „ „
2562·60	4sr	1	—	n = 6, „ „

SODIUM.

Salts used : Sodium Carbonate and Caustic Soda.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Remarks.
Wave-length.	Intensity.	Cone.	Flame.	
5896·16	10sr	50	50	n = 3, Pal. Ses.
5890·19	10sr	50	50	
5688·26	8n	8	8	n = 4, 2nd S. Ses.
5682·90	8n	7	7	
5675·92	2n	—	—	
5670·40	2n	—	—	
5153·72	6n	—	—	
5149·19	6n	—	—	
4983·53	6n	4	4	n = 5, 2nd S. Ses.
4979·30	6n	3	3	
4752·19	4n	—	—	
4748·36	4n	—	—	
4669·4	4n	2	2	n = 6, 2nd S. Ses.
4665·2	4n	2	2	
4546·03	2n	—	—	
4542·75	2n	—	—	
4500·0	2n			Traces in the continuous spectrum of the flame.
4994·3	2n			
3303·07	8r	10	10	n = 4, Pal. Ses.
3302·47	8r	10	10	
2852·91	6r	5	5	n = 5, „ „

POTASSIUM.

Salts used: Potassium Chloride and Caustic Potash.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Remarks.
Wave-length.	Intensity.	Cone.	Flame.	
7699·3	10nr	3	3	n = 3, Pal. Ses.
7665·6	10nr	4	4	
6938·8	8	—	—	—
6911·2	8	—	—	—
5832·23	4n	3	3	n = 5, 1st S. Ses.
5812·54	2n	1	1	
5802·01	6n	5	5	n = 5, 2nd ,, ,,
5782·67	6n	4	4	
5359·88	4n	3	3	n = 6, 1st ,, ,,
5343·35	2n	2	2	
5340·08	4n	2	2	n = 6, 2nd ,, ,,
5323·55	4n	1	1	
5112·68	2n	1	1	n = 7, 1st ,, ,,
5099·64	2n	1	1	
5097·75	1n	1	1	n = 7, 2nd ,, ,,
5084·49	2n	0·5	0·5	
4965·5	1n	Traces in the continuous spectrum of the flame.		n = 8, 1st ,, ,,
4956·8	1n			
4952·2	1n	Ibid.		n = 8, 2nd ,, ,,
4943·1	1n			
4870·8		Ibid.		n = 9, 1st ,, ,,
4863·8				
4856·8		Ibid.		n = 9, 2nd ,, ,,
4850·8				
4047·36	6r	20	20	n = 4, Pal. Ses.
4044·29	8r	20	20	
3447·49	6r	15	15	n = 5, ,, ,,
3446·49	8r	15	15	
3217·76	4r	10	8	n = 6, ,, ,,
3217·27	6r	10	8	

MAGNESIUM.

Salts used : Magnesium Chloride.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Remarks.
Wave-length.	Intensity.	Cone.	Flame.	
5528·75	6	—	—	
5183·84	10r	10	—	n = 3, 2nd S. Ses.
5172·87	10r	8	—	
5167·55	8r	7	—	
4703·33	8n	—	—	
4571·33	4	5	5	
4352·18	8n	—	—	
3838·44	10r	20	—	n = 4, 1st ,, ,,
3832·46	10r	15	—	
3829·51	10r	10	—	
3336·83	10n	7	—	n = 4, 2nd ,, ,,
3332·28	8n	5	—	
3330·08	8n	3	—	
3097·06	10r	—	—	n = 5, 1st ,, ,,
3093·14	8r	—	—	
3091·18	8r	—	—	
2942·21	8n	—	—	n = 5, 2nd ,, ,,
2938·67	6n	—	—	
2936·99	4n	—	—	
2936·61	4	—	—	
2928·74	4	—	—	
2915·57	4	—	—	
2852·22	10nr	50	20	This line is reversed (or double) in the flame spectrum

CALCIUM.

Salt used : Calcium Chloride.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Remarks.
Wave-length.	Intensity.	Cone.	Flame.	
4586·12	10	1	—	
4581·66	8	1	—	
4578·82	8	1	—	
4527·17	6	—	—	
4456·81	4	—	—	
4456·08	8r	—	—	n = 4, 1st S. Ses.
4454·97	10r	15	—	
4435·86	8r	} 12	—	n = 4, 1st ,, ,,
4435·13	10r			
4425·61	10r	8	—	n = 4, 1st ,, ,,
4355·41	6b	—	—	
4318·80	8r	8	—	
4307·91	8r	—	—	
4302·68	10r	7	—	
4299·14	6	—	—	
4289·51	8r	—	—	
4283·16	8r	—	—	
4240·58	4	—	—	
4226·91	10	50	50	
4098·82	4b^{v}	1	—	
4095·25	2b^{v}	1	—	
4092·83	2b^{v}	??	—	
3973·89	6b^{v}	—	—	n = 4, 2nd ,, ,,
3968·63	10r	4	—	H line
3957·23	6b^{v}	1	—	n = 4, 2nd ,, ,,
3949·09	4b^{v}	—	—	n = 4, 2nd ,, ,,
3933·83	10r	4	—	K line
3737·08	4	—	—	
3706·18	4	—	—	
3653·62	4	—	—	
3644·45	10r	2	—	n = 5, 1st ,, ,,
3630·82	8r	1	—	n = 5, 1st ,, ,,
3624·15	8r	??	—	n = 5, 1st ,, ,,

STRONTIUM.

Salt used : Strontium Chloride.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.	
Wave-length.	Intensity.	Cone.	Flame.	Wave-length.	Intensity.	Cone.	Flame.
5481·15	10	2	—	4832·23†	10r	5	—
5451·08	8	—	—	4812·01	10r	8	—
5257·12	10	1	—	4784·43	6	4	—
5238·76	10	0·5	—	4742·07	6	4	—
5229·52	8	—	—	4722·42	8	4	—
5225·35	8	—	—	4678·39	6n	—	—
5222·43	8	—	—	4607·52	10r	50	50
5156·37	10	—	—	4531·54	6	—	—
4968·11	8	—	—	4438·22	6n	—	—
4962·45	10r	4	—	4361·87	6n	—	—
4892·20	8	1	—	4338·00	$6b^v$	—	—
4876·35*	8r	4	—	4215·66	10r	6	5
4872·66	10r	4	—	4161·95	6	—	—
4868·92	6	—	—	4077·88	10r	6	5
4855·27	6	—	—	4030·45	$6b^r$	2	—

* n = 4, 1st S. Ses.

† n = 4, 1st S. Ses.

BARIUM.

Salt used : Barium Chloride.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.	
Wave-length.	Intensity.	Cone.	Flame.	Wave-length.	Intensity.	Cone.	Flame.
5535·69	10r	20	20	4402·75	8r	—	—
5519·37	8r	—	—	4350·49	8r	—	—
5424·82	8r	—	—	4283·27	8r	2	—
4934·24	10r	—	—	4130·88	8r	—	—
4900·13	8	—	—	3993·60	10r	6	—
4726·63	8r	—	—	3935·87	8r	—	—
4579·84	8r	—	—	3910·04	8r	—	—
4554·21	10r	4	—	3501·29	10r	8	—

ZINC.

Salt used : Zinc Chloride.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Remarks.
Wave-length.	Intensity.	Cone.	Flame.	
4810·71	10r	2	—	n = 3, 2nd S. Ses.
4722·26	10r	2	—	
4680·38	10r	1	—	
4630·06	8b^{v}	—	—	
4058·02	8	—	—	
3683·63	8b	—	—	
3345·62	8r	3	—	
3345·13	10r			n = 4, 1st ,, ,,
3303·03*	8r	2	—	n = 4, 1st ,, ,,
3202·67*	8r			
3282·42†	8r	?	—	n = 4, 1st ,, ,,
3075·99	8r	6	6	

* It cannot be distinguished which particular one of these two lines is present in the flame.

† This third component of the triplet is very feeble in the flame, if it exists at all. Possibly a longer exposure would have brought it out clearly. The homologous line at λ 3403·74 is seen on the photographs of the cadmium flame spectrum.

CADMIUM.

Salt used : Cadmium Chloride.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Remarks.
Wave-length.	Intensity.	Cone.	Flame.	
5086·06	10r	2	—	n = 3, 2nd S. Ses.
4800·09	10r	4	—	
4678·37	10r	4	—	
4662·69	8b^{v}	—	—	
3613·04	8r	1	—	n = 4, 1st ,, ,,
3610·66	10r	3	—	
3467·76	8r	1	—	n = 4, 1st ,, ,,
3466·33	10r	2	—	
3403·74	10r	1	—	n = 4, 1st ,, ,,
3261·17	10r	15	15	

The flame spectra of the six metals studied which belong to MENDELEEFF'S second group are characterized by the presence in each of them of one extremely strong line, whose brilliancy far surpasses that of any other line.

This line exists in the spectrum of every portion of the flame and has the wave-length :

2852·22	in the spectrum	of	magnesium,
3075·99	,,	,,	zinc,
3261·17	,,	,,	cadmium,
4226·91	,,	,,	calcium,
4607·52	,,	,,	strontium,
5535·69	,,	,,	barium.

If we classify these six elements into two sub-groups, the one containing magnesium, zinc, and cadmium, whose atomic weights are respectively 24·36, 65·4, and 112·4, the other containing calcium, strontium, and barium, whose atomic weights are 40, 87·6, and 137·4, it will be noticed that the wave-length of the line diminishes with the atomic weight of the element. It seems possible, therefore, that all these six lines correspond to each other. There seems no doubt on this point as regards the lines of magnesium, calcium, strontium, and barium. RYDBERG already unites these rays, and there is strong evidence that they should be grouped together. The correspondence of the other lines is more doubtful. Taking account of the displacements due to differences of atomic weight, it seems possible that the mercury line at 3650·31, which is strong in the arc, is the line corresponding to the above in the mercury spectrum.

MERCURY.

The attempts which have been made to obtain the flame spectrum of mercury have been unsuccessful. No lines of mercury have been seen in the flame into which has been blown the spray from solutions of metallic mercury in nitric acid, and from aqueous solutions of mercuric chloride to which sodium chloride has been added. M. GOUY has elsewhere stated the same fact.

It may be of interest to note that no mercury lines are present in the solar spectrum.

SILVER.

Salt used: Silver Nitrate.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. — Intensity.		Remarks.
Wave-length.	Intensity.	Cone.	Flame.	
5471·72	6	—	—	n = 4, 1st S. Ses. This line coincides in the flame with one of the lines of a carbon band
5465·66	10r	10	—	
5209·25	10r	3	—	n = 4, 1st S. Ses.
4668·70	$8b^{v}$	2	—	n = 4, 2nd ,, ,,
4476·29	$6b^{v}$	4	—	
4212·1	8r	5	Traces	n = 5, 1st ,, ,,
4055·44	6r	8	Traces	
3810·6	2n	4	—	n = 6, 1st ,, ,,
3681·8	$2b^{r}$	4	—	
3383·00	10r	50	50	
3280·80	10r	50	50	

Here only the lines of the arc spectrum which have an intensity at least 6 are indicated, since the lines 3810 and 3681 are the only ones of intensity less than 6 which are present in the flame.

Copper.

Salt used : Copper Nitrate.

Arc spectrum according to Kayser and Runge.		Flame spectrum. Intensity.		Remarks.
Wave-length.	Intensity.	Cone.	Flame.	
5782·30	8s	10	10	
5700·39	8s	3	—	
5218·45	10b^{r}r	5	—	
5153·33	8nr	3	—	n = 4, 1st S. Ses.
5105·75	8r	10	—	n = 4, 1st ,, ,,
4704·77	8s	?	?	This line coincides with a band
4651·31	8s	—	—	
4587·19	10n	—	—	
4539·98	8br	—	—	
4531·04	8b^{v}r	—	—	n = 4, 2nd S. Ses.
4480·59	8b^{v}r	—	—	n = 5, 2nd ,, ,,
4378·40	8r	—	—	
4275·32	8r	—	—	
4062·94	10b^{v}	?	?	This line coincides with a band
4022·83	10b^{v}	—	—	
3308·10	10b	—	—	
3274·06	10r	30	30	
3247·65	10r	30	30	
2961·25	—	4	—	Wave-length as given by Hartley
2766·50	6b^{v}r	3	—	
2618·46	10r	8	—	
2492·22	6r	3	—	
2441·72	6r	1	—	
2406·82	8b^{v}	—	—	
2392·71	8b^{r}	—	—	
2293·92	10r	—	—	
—	—	3	—	Line near 2292 . . . ?
2230·16	8r	—	—	
2228·95	4	2	—	
2227·85	8r	1	—	

Here, as in the case of silver, only the lines of the arc spectrum which have an intensity at least equal to 8 are given, notwithstanding the presence in the flame of certain lines which have an intensity less than 8 in the arc.

The flame spectrum of copper is extremely difficult to study on account of the presence of numerous bands, and the preceding table does not claim to be complete.

TIN.

Salt used : Protochloride of Tin.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.	
Wave-length.	Intensity.	Conc.	Flame.	Wave-length.	Intensity.	Conc.	Flame.
4524·92	8	10	0·5	2558·12	6b^{v}	—	—
3801·16	6r	10	0·5	2546·63	8r	10	—
3655·88	4	3	—	2531·35	6b^{v}	—	—
3330·71	6r	9	—	2524·05	4r	2	—
3262·44	8r	10	—	2495·80	8r	6	—
3218·78	4	—	—	2483·50	8r	8	—
3175·12	8r	10	3	2455·30	4	2	—
3141·92	4	—	—	2429·58	10r	10	—
3034·21	10r	12	3	2421·78	10r	7	—
3032·88	4r	—	—	2408·27	6r	2	—
3009·24	10r	10	3	2380·82	4r	3	—
2913·67	6r	—	—	2358·05	4	—	—
2863·41	10r	12	4	2354·94	10r	9	—
2850·72	6r	8	—	2334·89	8r	6	—
2840·06	10r	15	5	2317·32	10r	3	—
2813·66	4r	7	—	2286·79	6r	3	—
2812·70	4	—	—	2282·40	4	—	—
2788·09	6br	—	—	2269·03	10r	6	—
2785·14	4r	6	—	2267·30	6r	—	—
2779·92	6r	8	—	2251·29	6r	—	—
2706·61	10r	15	—	2246·15	10r	5	—
2661·35	6r	10	—	2231·80	6r	—	—
2637·05	4n	—	—	2209·78	10r	3	—
2594·49	6r	6	—	2199·46	10r	1	—
2571·67	8r	7	—	2194·63	8r	—	—

LEAD.

Salt used: Lead Nitrate.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.	
Wave-length.	Intensity.	Cone.	Flame.	Wave-length.	Intensity.	Cone.	Flame.
5005·62	$6b^{v}$	2	—	2663·26	6r	10	—
4168·21	4r	5	—	2650·77	8n	—	—
4062·30	4r	8	—	2628·36	2r	3	—
4057·97	10r	20	18	2614·26	8r	12	—
4019·77	4r	8	—	2613·74	4r	—	—
3740·10	8r	12	0·5	2577·35	6r	8	—
3683·60	10r	18	10	2476·48	6r	8	—
3671·65	4r	5	—	2446·28	6r	7	—
3639·71	10r	18	10	2443·92	6r	7	—
3572·88	8r	12	0·5	2428·71	6r	—	—
3262·47	6	—	—	2411·80	6r	2	—
3240·31	6	—	—	2402·04	6r	7	—
3220·68	6	—	—	2399·69	4r	—	—
3150·9	4n	—	—	2393·89	8r	7	—
2873·40	6r	8	0·5	2388·89	4r	—	—
2833·17	10r	7	0·5	2332·54	6r	—	—
2823·28	6r	9	2	2254·02	4r	—	—
2802·09	8r	12	3	2247·00	10r	2	—
2697·72	6rn	—	—				

BISMUTH.

Salt used: Bismuth Sub-Nitrate dissolved with dilute Nitric Acid.

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.	
Wave-length.	Intensity.	Cone.	Flame.	Wave-length.	Intensity.	Cone.	Flame.
4722·72*	10r	10	10	2989·15	8r	9	—
4122·01	6	} 7	—	2938·41	10r	9	—
4121·69	6			2898·08	10r	9	—
3596·26	4r	5	—	2863·86	4	—	—
3511·00	4r	5	—	2809·74	8r	—	—
3397·31	4r	8	—	2798·75	4	—	—
3067·81	10r	7	4	2780·57	8r	3	—
3034·99	$4b^{v}$	—	—	2730·61	6r	—	—
3024·75	8r	9	—	2696·84	6r	—	—
2993·46	8r	5	—	2627·99	8r	5	—

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* It is probable that the spectrum of bismuth, which is very feeble compared with those of the other metals, would be improved if photographed under different conditions, *e.g.*, if a different salt were used and the time of exposure were prolonged.

CHROMIUM.

The spectrum of this metal, obtained by using a concentrated solution of chromic acid, only shows, besides an extremely intense continuous spectrum which occupies the whole visible portion up to about 3300, the four following triplets :—

Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.		Arc spectrum according to KAYSER and RUNGE.		Flame spectrum. Intensity.	
Wave-length.	Intensity.	Conc.	Flame.	Wave-length.	Intensity.	Conc.	Flame.
5208·58	10nr	5	2	3605·46	10nr	14	9
* 5206·20	10nr	4	1	* 3593·57	10nr	14	9
5204·67	10nr	3	1	3578·81	10nr	14	9
4289·87‡	10nr	15	8	3021·68	2	8	—
* 4274·91	10nr	15	8	† 3017·66	2	8	—
4254·49	10nr	15	8	3015·05	2	8	—

* According to the determination of M. HASSELBERG.

† According to determinations by MM. EXNER and HASCHEK.

‡ This triplet and the following are probably two terms of a series; in fact, their appearances in the flame spectrum are identical. Moreover, the differences between the wave numbers $\left(\frac{1}{\lambda}\right)$ of the first two lines of each of them are respectively 82 and 92, and between the wave numbers of the second and the third lines, 112 and 114 respectively.

SUMMARY OF RESULTS.

An inspection of the preceding tables will have shown that the lines in the spectra produced under the conditions of my experiments are much more numerous than is the case when the salt spray is not previously mixed with the gases which react to form the flame, but is introduced in some other manner. In the latter case it does not really enter into that zone of flame where the most intense chemical reactions are occurring and where the temperature is most elevated. Two different causes might be suggested in order to explain this increase in the number of the lines.

The flame is divided into two quite distinct portions : an inner one which is reducing in its action, and another one which is oxidizing on account of the presence of air in excess. In the working of the sprayer the metallic salt is forced to pass in succession through these two regions, *i.e.*, from the reducing region to the oxidizing region. It is possible that, during the passage across the boundary separating these two regions, there is a period, possibly very short, in which the metal, liberated from its combination, exists in the state of metallic vapour. The atom is at this moment in the hottest portion of the flame, namely, that which surrounds the blue inner cone and which is surrounded itself by the external portion of the flame. Here it may undergo a breaking-up, or in any case a modification of its physical or chemical constitution. In support of this view, one might mention the great changes produced in all the properties of iron, even in the solid state, by variations of temperature of much smaller range than those which occur in the flame. The metallic vapour, thus modified, passes in succession through zones of the flame of gradually decreasing temperature, and in which it exists in other intermediate states which might be called "states of less advanced dissociation."

The following observation will serve to give a clearer idea of this method of considering the phenomena. If by means of a short-focus lens a small image of the flame is thrown on to the slit of the spectroscope, so that the whole length of the image is less than that of the slit, then it will be found, as for example in the case of potassium, that the spectrum is divided longitudinally into three well-defined parallel strips. In the lower strip, which corresponds to the blue cone of the flame, all the lines will be found together with the band spectrum of carbon. At the upper edge of the central band the five groups of four extremely close lines, which belong to the two secondary series of potassium, will be seen to terminate; also the continuous spectrum which accompanies the line spectrum ends at this edge. Now it is precisely the point in the flame corresponding to the upper edge of this strip which marks the termination of what is considered to be the hottest zone of the flame, namely, the part surrounding the blue cone and which appears to the eye to be more luminous than the other portions. The third horizontal strip, corresponding to the highest portions of the flame, contains only the strongest lines of the principal series of the metal standing out from a completely dark background.

In the case of other metals whose more complex spectra have not yet been divided into series, considerable differences have been found, as the tables show, in the intensities of one and the same line depending upon whether this line has been produced in the neighbourhood of the base or in the upper regions of the flame. Certain of their lines even exist only in the neighbourhood of the blue cone. It is very probable that an examination of the relative lengths of the lines and of their appearance would result in the determination of new series. In fact, in the spectrum of the alkaline metals and of those metals whose flame spectra do contain known series, a complete analogy is seen in the appearances of those lines whose wave-lengths are connected with one another by some numerical relation. I have elsewhere (p. 160) pointed out in the flame spectrum of chromium the presence of two triplets which are probably members of the same series.

If we now compare the flame spectra thus produced with those of the arc and the spark, it will be noticed that as a rule the lines which are found in the flame spectrum are those which are the strongest lines in the arc spectrum. In certain cases, some of the more intense arc lines are absent, whereas less intense arc lines are to be found in the flame spectrum. On the other hand, none of the characteristic lines of the spark spectrum are ever seen in the flame spectrum. The resemblance, however, is very marked between the flame spectrum and that of the spark, in which the oscillatory character is controlled by the introduction of a self-induction into the discharging circuit of a condenser, and which for the sake of brevity may be called an oscillatory spark. In the latter case, as is well known from the work of Dr. HEMSALECH, the spark spectrum is considerably simplified. Moreover, although the flame spectrum will contain only the lines which belong to the spectrum of the oscillatory spark, yet all the lines of the latter will not be found in the flame spectrum, the missing lines being those which are peculiar to the ordinary spark spectrum, and which only exist in the immediate neighbourhood of the electrodes, becoming shorter and shorter, and finally disappearing as the self-induction is increased.

The preceding paragraph refers to metals other than those belonging to the iron group. On the contrary, there is a most striking similarity between the flame spectra of iron, of nickel and of cobalt and the oscillatory spark spectra of the same metals in the region included between about 4300 and 2700 Ångström units. The similarity of the two spectra is so great that, except for very small differences of intensity, the oscillatory spark spectrum, which is photographed as a comparison spectrum in the centre of the flame spectrum, appears to be a prolongation of the latter. This may be seen in the photographs placed at the end of this paper.

It should be noticed that if in the visible portion of the spectrum certain lines appear to be missing, it is probably because the continuous spectrum which appears in this region of the spectrum prevents these feeble lines from being seen. This may explain why M. GOUY was not able to observe the nickel lines which are found on the photographs taken with various salts of nickel, viz., the sulphate, chloride, and ammoniacal chloride. In the ultra-violet the spectrum of the flame appears to fade away a little more rapidly than that of the oscillatory spark, but it is probable that this difference would be reduced by prolonging the time of exposure; since it is, of course, the radiations of the shortest wave-length which are most absorbed by different media.

What are the reasons for this similarity between the spectrum of the flame and the spectrum of the oscillatory spark? Until we have conclusive evidence to the contrary, we must assume that it is a question of temperature. On the one hand, the increase in the number of lines of the flame spectrum obtained by the use of the sprayer may be attributed to the fact that the hottest regions of the flame take part in the production of the phenomena, and, on the other hand, the diminution in the number of lines in the spark spectrum when the spark becomes oscillatory is due to a diminution of its temperature. In fact, in the case of the ordinary spark, the whole of the energy liberated in the secondary circuit of the induction coil by the breaking of the current in the primary circuit is dissipated in a single rush; whereas, in the case of the oscillatory spark, the rate of dissipation is greatly reduced by the conditions under which the discharge takes place. It is really the temperature at the point at which the discharge current leaves the electrode and enters the air which plays the most important part in the production of the spectrum, and not the general temperature of the spark itself. It is obvious that the greater the resistance to the passage of the current at this point the greater will be the amount of heat liberated there. The experiments of Professor HARTLEY* and M. SCHENK,† who observed that what are considered to be the high-temperature lines of the spark spectrum disappeared when the electrodes were heated to incandescence, do not prove that this was the real reason; for, since the electrodes were heated artificially, the air between them would be rendered conducting. Hence there would be less resistance to the passage of the discharge, and therefore a less amount of heat produced there, so that the high-temperature lines would be expected to disappear under the circumstances.

We cannot suppose that the oscillations themselves play any part of electrical nature in the production of the lines in the spectrum of the oscillatory spark, since the only effect of the self-induction is to suppress existing lines and not to introduce new lines in the spectrum. If certain lines are increased in brilliancy by the introduction of self-induction, as in the case of the spectra of metals of the iron group, we may conclude, with Dr. HEMSALECH, that here the effect of the oscillations is to raise the temperature of the vapour already formed between the electrodes by the initial discharge.‡ Since the amount of heat liberated in this initial discharge is less than it would be in the case of the non-oscillatory discharge, the vapour will be in a state of less advanced dissociation; but if the amount of heat liberated in the succeeding discharges is more than sufficient to compensate for the loss by radiation, which must be considerable on account of the high temperature of the vapour, then the temperature of the vapour will be increased and consequently also the intensity of some of the lines.

It seems to me that a satisfactory explanation of the phenomena I have observed may be obtained by considering them as the results simply of variations of temperature. Of course, it cannot be denied that spectra may be formed by other means than a pure and simple elevation of temperature, but these methods ultimately reduce themselves to chemical transformations and thermal changes. This temperature hypothesis, which accounts in the simplest way for the production of the spectra, finds considerable support in the fact that the stars give spectra which are similar in their constitution to those obtained in the laboratory by electrical methods. It is difficult to imagine any other but a purely thermal cause for the luminosity of stars.

In conclusion, I wish to express my best thanks to Professor SCHUSTER for his kindness in placing the resources of his splendid laboratory at my disposal and for the advice he has given me during this work. My thanks are also due to Mr. R. S. HUTTON and Dr. HEMSALECH for the help they have given me.

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* 'Phil. Trans.,' 1882.

† 'Astrophys. Journal,' 14, pp. 116–135, 1901.

‡ *Loc. cit.*, p. 11.

Addition, received August 29, 1904.

IRON.

Flame Spectrum (Wave-lengths according to KAYSER and RUNGE).

Wave-lengths.	Intensity.		Wave-lengths.	Intensity.		Wave-lengths.	Intensity.	
	Cone.	Flame.		Cone	Flame.		Cone.	Flame.
5615·81*			4443·30	2	—	4175·71	2	—
5586·92*			4442·46	2	—	4172·20	traces	—
5455·80	1	—	4427·44	8	6	4170·99	traces	—
5447·05	1	—	4415·27	7	1	4158·89	1	—
5434·66	2	—	4404·88	9	4	4157·91	1	—
5429·74	1	—	4383·70	10	6	4156·88	3	—
5405·91	2	—	4376·04	7	6	4154·95	3	—
5397·27	2	—	4337·14	1	—	4154·57		
5383·50	0·5	—	4325·92	9	5	4154·04		
5371·62	4	3	4307·96§	8	5	4149·44	traces	—
5328·15	5	4	4299·42	5	—	4147·74	traces	—
5270·43†	6	5	4294·26	2	—	4143·96	8	4
5269·65			4282·58	4	—	4143·50		
5233·05	1	—	4271·93	8	6	4137·06	1	—
5227·33	1	—	4271·30			4134·77	4	—
5227·00			4260·64	7	1	4132·96	1	—
5192·47	1	—	4250·93	5	2	4132·15	6	2
5167·50	1	—	4250·28			4127·68	2	—
5139·58	1	—	4247·60	1	—	4126·25	traces	—
5139·34			4238·98	1	—	4118·62	5	—
4957·80	5	—	4236·09	6	—	4114·53	1	—
4957·43			4233·76	4	—	4109·88	3	—
4920·63	4	—	4227·60	5	—	4107·58	3	—
4919·11			4222·32	3	—	4098·26	1	—
4891·62	4	—	4219·47	2	—	4096·06	1	—
4890·89			4217·69	1	—	4085·38	2	—
4872·25	3	—	4216·28	2	—	4085·07		
4871·43			4210·48	3	—	4084·59	2	—
4859·86	1	—	4202·15	4	2	4079·91	traces	—
4736·91‡			4199·19	4	1	4078·41	traces	—
4528·78	3	—	4198·42	4	1	4076·72	3	—
4494·67	2	—	4196·31	traces	—	4074·87	traces	—
4489·84	2	1	4195·46	traces	—	4073·84	traces	—
4482·35	4	3	4191·57	4	—	4071·79	10	5
4476·20	2	—	4187·92	4	—	4068·07	2	—
4466·70	2	—	4187·17			4067·36	2	—
4461·75	5	4	4184·99	1	—	4067·04		
4459·24	1	—	4181·85	4	—	4063·63	10	6
4447·85	0·5	—	4176·62	traces	—	4063·40	1	—

* Coincides with bands. † E line. ‡ Coincides with a carbon band. § G line.

Iron—continued.

Wave-lengths.	Intensity.		Wave-lengths.	Intensity.		Wave-lengths.	Intensity.	
	Cone.	Flame.		Cone.	Flame.		Cone.	Flame.
4058·30	1	—	3878·82	10	10	3737·27	8	8
4045·90	15	7	3878·12	10	10	3735·45	8	6
4024·86	1	—	3873·88	1	—	3735·00		
4021·96	4	—	3872·61	6	3	3733·46	6	6
4017·23	1	—	3869·69	traces	—	3732·54	1	—
4014·63	4	—	3867·33	1	—	3727·78†	6	3
4009·80	4	—	3865·65	6	3	3727·13†	1	—
4007·36	traces	—	3860·03	10	10	3724·51	traces	—
4005·33	8	3	3859·34			3722·69	6	6
3998·16	3	—	3856·49	9	9	3720·07	8	8
3997·49	3	—	3852·71	1	—	3718·55	2	—
3996·08	traces	—	3850·96	1	—	3716·59	3	—
3994·22	1	—	3850·11	5	3	3711·35	1	—
3984·08	1	—	3846·96	2	—	3709·37	7	3
3981·87	1	—	3845·30	traces	—	3708·03	6	3
3977·83	3	—	3843·40	2	—	3705·70	8	8
3976·71	1	—	3841·19	7	3	3704·59	traces	—
3971·41	2	—	3840·58	7	3	3701·20	4	—
3969·34	8	traces	3839·38	2	—	3697·58	1	—
3967·51	2	—	3834·37	7	5	3694·13	2	—
3966·70	2	—	3827·96	7	2	3689·58	2	—
3966·16	2	—	3826·04	7	5	3687·58	6	3
3963·24	2	—	3824·58	7	7	3686·10	2	—
3956·77	5	—	3820·56*	7	6	3684·24	traces	—
3953·25	2	—	3815·97	7	2	3683·18	*id.*	3
3952·71	2	—	3813·12	4	2	3682·35	*id.*	—
3951·25	2	—	3807·68	3	—	3680·03	6	8
3950·05	2	—	3806·84	2	—	3677·76	2	—
3948·87	2	—	3805·47	1	—	3670·20	2	—
3942·54	traces	—	3799·68	4	1	3651·61	3	—
3940·98	traces	—	3798·65	3	1	3649·65	2	—
3930·37	10	10	3797·65	2	—	3647·99	7	5
3928·05	10	10	3795·13	4	1	3640·53	4	—
3926·05	1	—	3790·22	2	—	3638·44	1	—
3925·74			3788·01	4	1	3631·62	8	5
3923·00	10	10	3786·81	2	—	3621·61	5	—
3920·36	10	10	3786·30	2	—	3618·92	8	5
3918·74	2	—	3786·07			3617·94	2	—
3918·49			3767·31	6	3	3610·29	4	—
3917·29	1	—	3765·66	3	—	3608·99	8	5
3916·82	1	—	3763·90	6	3	3606·83	5	—
3906·58	7	7	3760·66	traces	—	3605·62	4	—
3903·06	6	traces	3760·17	traces	—	3603·34	2	—
3899·80	9	9	3758·36	7	4	3594·71	3	—
3898·05	2	—	3753·74	1	—	3589·25	traces	—
3895·75	9	9	3749·61	8	4	3587·10	5	traces
3888·63	6	—	3748·39	6	6	3585·43	7	traces
3887·17	2	—	3745·95	8	8	3581·32‡	8	8
3886·38	12	12	3745·67			3575·49	1	—
3884·46	1	—	3743·45	4	—	3574·00	1	—
3883·39	1	—	3738·44	1	—	3572·12	1	—

* L line.　　† M line.　　‡ N line.

IRON—continued.

Wave-lengths.	Intensity.		Wave-lengths.	Intensity.		Wave-lengths.	Intensity.	
	Cone.	Flame.		Cone.	Flame.		Cone.	Flame.
3570·23	9	7	3402·33	1	—	3212·08	7	—
3565·50	9	4	3401·60	1	—	3210·92	8	—
3558·62	5	2	3399·39	6	—	3210·35		
3556·99	3	—	3394·65	1	—	3209·45	5	—
3555·04	6	—	3392·74	7	—	3208·60	2	—
3545·74	1	—	3384·05	3	—	3205·45	6	—
3542·20	6	—	3380·17	2	—	3200·58†	8	—
3541·22	6	—	3379·11	2	—	3199·62†	8	—
3538·01	2	—	3370·87	5	—	3197·04	7	—
3537·84			3369·62	3	—	3192·93	8	—
3536·65	6	—	3366·88	2	—	3191·77	5	—
3533·30	6	—	3342·35	1	—	3188·96	3	—
3529·90	2	—	3337·73	1	—	3188·67		
3527·90	1	—	3335·85	1	—	3185·00	3	—
3526·51	8	6	3329·00	1	—	3180·30‡	8	—
3526·25			3323·84	2	—	3178·08†	—	—
3524·34	1	—	3314·86	4	—	3175·53†	—	—
3524·15			3306·50	10	—	3165·97†	—	—
3521·36	7	—	3298·25	2	—	3162·04†	—	—
3513·91	6	—	3292·70	4	—	3160·74†	—	—
3497·92	7	6	3292·13	4	—	3160·37†	—	—
3497·20	2	—	3291·10	3	—	3156·35†	—	—
3495·37	2	—	3286·87¶	8	—	3153·31†	—	—
3490·65	8	8	3280·37	4	—	3151·42†	—	—
3480·45	2	—	3274·05	4	—	3132·61†	—	—
3476·75	7	7	3271·12	7	—	3120·95	2	—
3475·52	8	8	3265·73	6	—	3120·54		
3471·40	1	—	3260·09	4	—	3119·58†	—	—
3465·95	8	8	3257·69	4	—	3116·73	3	—
3460·02	1	—	3254·47	4	—	3100·77§	20	—
3458·39	1	—	3251·31	2	—	3100·38§		
3452·35	4	—	3250·75	3	—	3100·04§		
3450·41	3	—	3248·31	2	—	3091·67†	—	—
3447·37	2	—	3247·70	5	—	3083·81†	—	—
3445·22	6	—	3247·39			3075·80†	—	—
3443·96	6	6	3244·27	7	—	3067·30†	—	—
3441·07*	10	10	3239·53	6	—	3059·19	6	4
3440·69			3234·07	4	—	3057·55	10	—
3428·26	2	—	3233·14	4	—	3055·35	4	—
3427·21	7	—	3231·05	4	—	3053·15	4	—
3426·44	2	—	3230·29	4	—	3047·71‖	7	4
3424·36	3	—	3228·36	6	—	3045·16	3	—
3422·69	3	—	3225·90	8	—	3042·75	6	—
3418·58	3	—	3222·12	8	—	3041·83	8	—
3417·92	3	—	3219·92	7	—	3040·54	6	—
3414·83	1	—	3219·67			3037·54	7	3
3413·22	6	—	3217·49	5	—	3037·37		
3407·55	8	—	3216·03	6	—	3031·74	6	—
3406·88	2	—	3214·14	8	—	3031·31	6	—
3404·41	5	—	3213·43	3	—	3030·24	6	—

* O line. † Coincides with a H^{2}O line. ‡ R line.

§ S$_2$ line. ‖ *s* line. ¶ Q line.

Iron—continued.

Wave-lengths.	Intensity.		Wave-lengths.	Intensity.		Wave-lengths.	Intensity.	
	Cone.	Flame.		Cone.	Flame.		Cone.	Flame.
3026·57	6	—	2912·26	7	—	2764·41	4	—
3025·75	9	2	2902·02‖			2763·17	4	—
3024·13	5	—	2901·46‖			2762·12	8	—
3021·15*	12	6	2899·49	6	—	2759·86	5	—
3020·70*			2894·59	4	—	2757·38	7	—
3019·08	9	—	2893·97	6	—	2756·36	6	—
3017·72	4	—	2883·80	6	—	2754·48	4	—
3016·29	6	—	2881·65	4	—	2754·09	5	—
3016·04			2880·84	5	—	2753·74	5	—
3011·57	5	—	2877·37	6	—	2750·95	4	—
3009·66	9	—	2874·98	8	—	2750·21	6	—
3009·18	3	—	2874·24	3	—	2747·03	4	—
3008·23	5	2	2872·38	3	—	2744·60	6	—
3007·30	6	—	2869·38	4	—	2744·12	5	—
3003·14	7	—	2866·68	2	—	2743·63	5	—
3001·05	7	3	2863·92	6	—	2742·45	8	—
2999·61	9	—	2863·46			2737·37	5	—
2996·49	3	—	2858·96	4	—	2735·71	7	—
2994·54†	7	3	2851·85	10	—	2734·39	1	—
2991·78	2	—	2848·77	2	—	2733·65	8	—
2990·48	5	—	2845·63	6	—	2731·04	4	—
2987·40	7	—	2844·04	9	—	2728·90	4	—
2984·92	3	—	2840·50	3	—	2728·11	5	—
2983·68	7	3	2838·19	6	—	2726·20	6	—
2981·54	6	—	2835·51	4	—	2724·97	5	—
2973·41	9	4	2832·47	8	—	2723·66	6	—
2973·17			2828·87	4	—	2720·99	6	—
2970·20	5	traces	2825·60	6	—	2720·28	2	—
2969·52	6	—	2823·32	6	—	2719·51	2	—
2966·99	7	4	2817·55			2719·11	5	—
2965·35	5	—	2813·36	8	—	2718·51	6	—
2960·39	5	—	2812·09	8	—	2717·84	1	—
2960·07			2804·56	8	—	2711·71	6	—
2957·57	6	traces	2797·82	7	—	2710·61	4	—
2953·99	7	1	2795·58	4	—	2708·64	5	—
2953·86			2795·00	4	—	2706·63	7	—
2953·59			2792·44	1	—	2706·07	5	—
2950·34	7	—	2791·84	3	—	2699·18	6	—
2948·00¶	8	1	2789·87	2	—	2697·08	3	—
2944·49	3	—	2788·05	10	—	2696·41	3	—
2941·42	6	—	2778·89	3	—	2696·12	3	—
2936·99	7	—	2778·29	7	—	2695·64	3	—
2929·20	7	1	2774·76	4	—	2695·12	2	—
2926·65	7	—	2773·28	2	—	2694·63	3	—
2923·94	2	—	2772·15	7	—	2692·71	2	—
2923·39	2	—	2769·37	4	—	2689·92	4	—
‡2920·76§	—	—	2767·56	7	—	2689·28	7	—
2918·11§	—	—	2766·99	4	—	2684·10	3	—

* T line. † *t* line.

‡ Between 2920 and 2820 the observation is much impeded by the presence of strong bands of water-vapour. § Coincides with a H^2O line. ‖ ? ¶ *u* line.

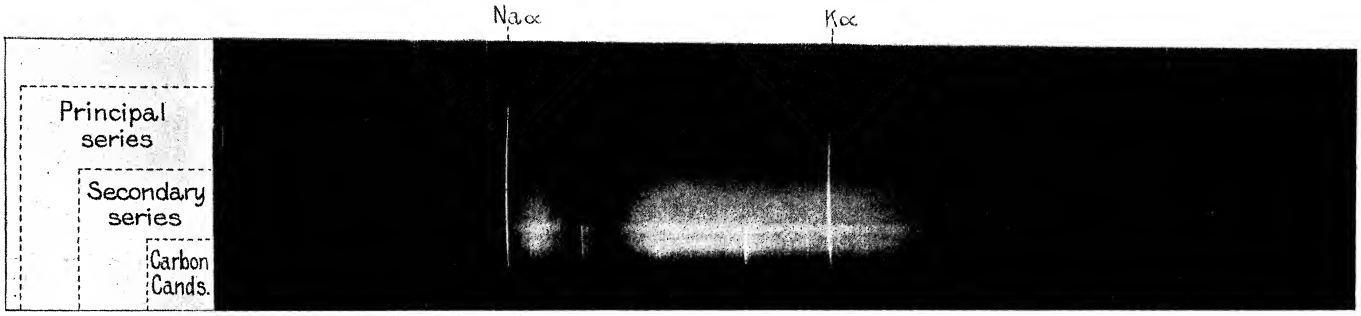
IRON—continued.

Wave-lengths.	Intensity.	
	Cone.	Flame.
2681·62	2	—
2680·99	1	—
2680·53	3	—
2679·14	7	—
2673·28	3	—
2669·55	3	—
2667·05	7	—
2666·94		
2664·16	4	—
2662·13	4	—
2656·22	4	—
2647·64	2	—
2644·07	7	—
2641·74	5	—
2636·54	3	—
2635·87	7	—
2632·66	2	—
2632·30	6	—
Traces of weak Fe or H^2O lines.		
2623·58	8	—
2618·10	7	—
2611·94	2	—
2607·16	8	—
2605·77	3	—
2599·53	8	—
2594·20	4	—
2588·11	6	—
2584·59	10	—
2582·50	5	—
2576·76	7	—
2575·83	5	—
2569·73	2	—
2568·97	1	—
2556·92	3	—
2556·38	3	—
2552·74	5	—
2551·19	6	—
2549·63	8	—
2546·26	8	—
2544·83	6	—
2544·02	7	—
2542·20	7	—
2541·18	6	—
2540·90	4	—
2539·48	4	—
2537·21	7	—
2536·90	2	—
2535·67	8	—
2533·86	3	—
2530·79	6	—
2530·03	6	—
2529·40	9	—
2527·67	9	—
2525·11	3	—
2524·32	7	—
2523·76	6	—
2522·67	9	—
2521·97	3	—
2519·71	7	—
2518·25	7	—
2517·76	7	—
2517·25	1	—
2516·65	1	—
2512·38	7	—
2511·05	8	—
2507·99	9	—
2505·09	2	—
2501·87	4	—
2501·00	6	—
2496·60	9	—
2496·01	3	—
2494·10	5	—
2491·50	8	—
2490·98	8	—
2490·01	8	—
2488·23	7	—
2487·18	5	—
2486·77	5	—
2486·42	4	—
2486·04	2	—
2484·35	7	—
2483·34	8	—
2479·64	8	—
2476·77	5	—
2474·88	9	—
2473·15	7	—
2472·40	8	—
2471·05	2	—
2468·97	9	—
2467·80	4	—
2465·23	9	—
2463·86	2	—
2462·81	4	—
2462·30	3	—
2457·68	9	—
2453·57	5	—
2447·81	2	—
2443·94	4	—
2442·68	2	—
2440·25	traces	—
2439·82	4	—
2438·27	3	—
2490·03	1	—
2482·15	1	—
2473·79	1	—
2471·51	traces	—
2320·42	1	—
2312·40	1	—
2309·05	1	—
2303·52	1	—
2298·24	2	—
2297·85		
2293·90	traces	—
2287·37	*id.*	—
2283·15	*id.*	—
2265·05	*id.*	—

DESCRIPTION OF PLATE 4.

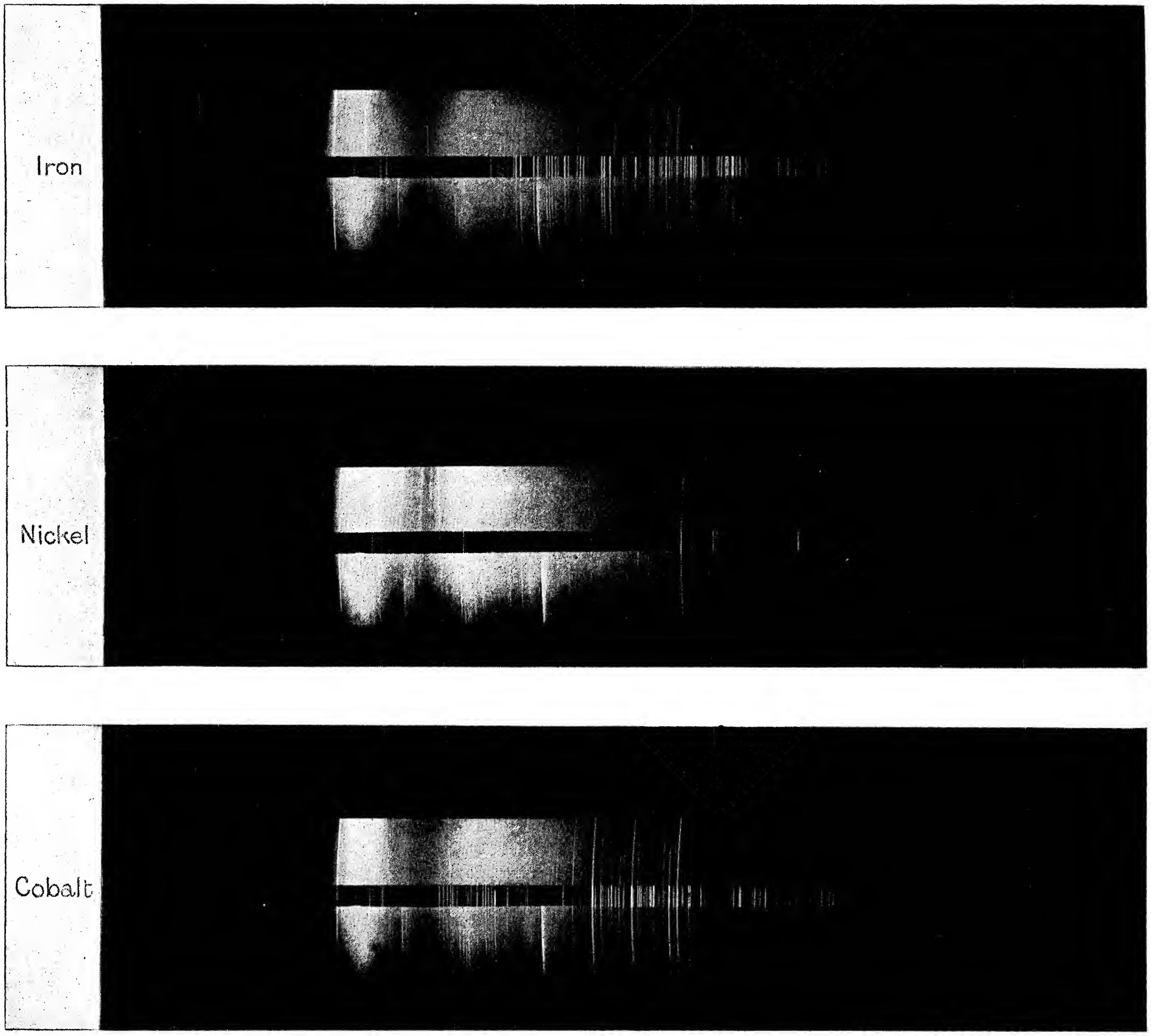
1. Flame spectrum of potassium (see p. 161).

2, 3, 4. Spectra of iron, nickel, and cobalt. In the centre of each of them the oscillatory spark spectrum divides the flame spectrum in two regions of which the one corresponds to the inner cone, while the other corresponds to the upper portion of the flame.



1

Spectrum of potassium.



2

3

4

Comparison of the spectrum of the flame and the oscillatory electric spark.

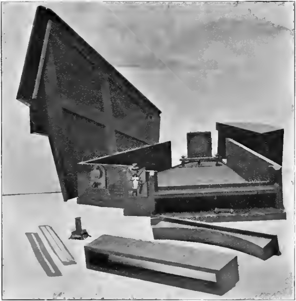
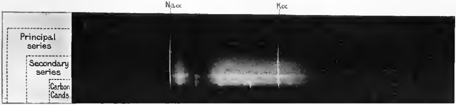
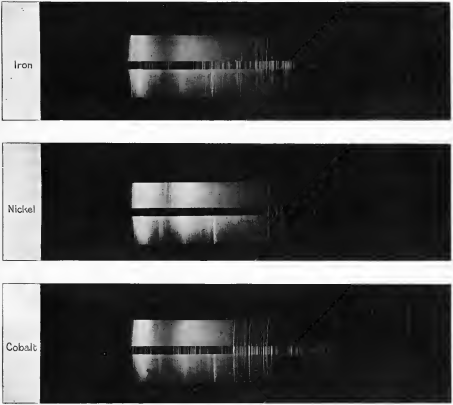


Fig. 2.



1

Spectrum of potassium.



2

3

4

Comparison of the spectrum of the flame and the oscillatory electric spark.